KANSAS VAPOR INTRUSION GUIDANCE

Chemical Vapor Intrusion
And
Residential Indoor Air

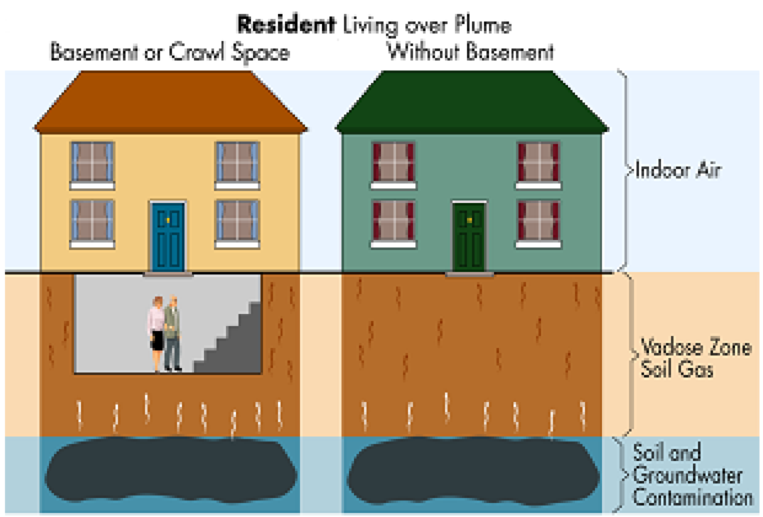

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TABLE OF CONTENTS

Cover image courtesy of the Interstate Technology and Regulatory Council's (ITRC) Technical and Regulatory Guidance document, *Vapor Intrusion Pathway: A Practical Guide* (VI-1, 2007)

Introduction

Sites contaminated with volatile organic compounds (VOCs) are potential public health hazards. Contact with VOC contaminated soil and ground water have been widely recognized as pathways of potential human exposure. Another pathway, known as vapor intrusion, involves VOC migration from contaminated soil and/or ground water into nearby structures, i.e. houses, schools, etc. Vapor intrusion is by far the most difficult and complicated pathway to evaluate for human exposure. Changing atmospheric conditions such as wind, pressure, temperature and precipitation rapidly affect indoor air concentrations as well as the type of structure, building characteristics, furnace type, and other building specific parameters. Although measurable concentrations in indoor air are not seen at every VOC contaminated site, the efficiency of inhalation exposure makes it important to investigate vapor intrusion as a potential pathway. Health risks associated with breathing VOCs are greater than from drinking comparably contaminated water. The Kansas Department of Health and Environment(KDHE), Bureau of Environmental Remediation (BER) has developed this guidance document for environmental consultants and contractors addressing chemical vapor intrusion questions.

1. Document Purpose

This document is intended to assist staff, and also environmental consultants and contractors working on sites in KDHE programs, in understanding the basic concepts of chemical vapor intrusion and the importance of addressing this potential public health issue. The guidance in this document should not be interpreted to contradict existing guidance and regulations related to the investigation and remediation of contaminated sites.

This document does not represent new policy. It was developed to describe existing BER policy and practice for evaluating impacts to indoor air quality from chemical vapor intrusion. Every site presents unique circumstances and sites will be addressed on a site by site basis as determined by the KDHE project manager. BER has dealt with indoor air issues since the late 1980's, most in the form of odor complaints, and is rapidly refining policy to ensure current vapor intrusion issues are being addressed.

2. How Vapor Intrusion Occurs

Vapor intrusion occurs when VOCs migrate from contaminated ground water or soils to the indoor air of a building. Any VOC-contaminated site has the potential for vapor intrusion. Sites contaminated by petroleum releases from leaking underground storage tank systems and sites contaminated by chlorinated solvents represent the two most common vapor intrusion scenarios. Sites contaminated with chlorinated solvents are much more complicated to evaluate for vapor intrusion because of the greater mobility of the contaminant, potential lack of accompanying odor, and lack of degradation.

Several factors must be present for vapor intrusion to impact indoor air and cause exposures of public health concern. Some conditions that affect this exposure pathway are as follows:

Building Features

- Construction style - Vapor intrusion may occur in any building type. Previous thought was that impacts were limited to structures with basements, however, BER and other state environmental agencies have determined that all types of buildings are susceptible to vapor intrusion. The condition of the foundation, furnace type and location, and building ventilation appear to be more important factors in susceptibility.

- Type of building – whether the structure is residential or commercial may influence vapor migration. HVAC systems may be designed differently for commercial buildings (e.g. positively pressured, etc.) and limit the potential for vapor intrusion.

- Age of the structure - Older buildings are more likely to have foundations that have developed cracks and other entry points for vapor intrusion, but are less airtight, allowing more fresh air exchanges. Newer buildings have better constructed foundations and are more airtight with less fresh air exchanges, which could lead to higher concentrations in the occupied spaces and possibly an increase of contaminant migration into the structure.

- Dirt floors and stone foundations - Earthen floors, concrete block, limestone or field stone foundations are more porous and provide increased opportunity for vapor intrusion compared to poured concrete foundations.

- Drain tiles / sumps - If the building has a foundation drain tile connected to a sump a direct conduit exists from the subsurface to the indoor air. If the sump is active, even low VOC concentrations in ground water can contribute to significant indoor air problems. As the water flows over the ridged drain tile and then into the sump, much of the VOC mass can be effectively stripped from the water (particularly for VOCs with high Henry's Law Constants), and then into the head space of the tile, sump and indoor air.

- Wet basements - If the building has chronic water intrusion problems, VOCs dissolved in water infiltrating into the basement will off-gas to indoor air. Periodic water problems can be related to improper landscaping and drainage, but may also indicate a shallow water table.

- Utility lines / preferential pathways - Gaps or cracks around piping or other utility lines that enter through the foundation can be a preferential migration path for vapor intrusion. Permeable soil in a utility trench can also provide a conduit through which contaminants may migrate greater distances from the source area.

- Elevators – Buildings with elevators may have an increased likelihood of vapor intrusion due to the elevator shaft and the pumping or vacuum effect of the elevators' travel.

Environmental Conditions

- Proximity of contaminant source to buildings - Vapor intrusion is a greater concern when buildings are very close (<100 ft.) to the source of VOC contamination. Vapor migration from soil is commonly associated with extremely high concentrations or saturation. A secondary source could be contaminated ground water.

- Shallow ground water - The potential for vapor intrusion decreases with increasing depth to ground water. The U.S. Environmental Protection Agency (EPA) suggests that vapor intrusion cannot be safely ruled out when the ground water table is less than 100 feet from the surface. KDHE will prioritize and focus on sites with ground water depths of 40 feet or less.

- Soil type - Soil type greatly influences the transport of vapors in soil. Coarse-grained soil types can allow contaminant migration over long distances, but also provide easier venting to the atmosphere. Fine grained or tight soils inhibit long distance migration, but increased capillarity allows greater vertical contaminant transport. The spatial arrangement of soil type features is as important as the presence of various soil types.

- Fractured bedrock - Shallow fractured bedrock can increase vapor intrusion potential by allowing faster soil gas migration and movement of contaminated ground water. Contamination migration endpoints are less predictable in this media. Additional sampling may be necessary when dealing with fractured bedrock sites.

- Degradation - Petroleum hydrocarbons biodegrade readily in unsaturated soils. Therefore, petroleum-related VOCs generally have to be present in extremely high concentrations or very near the building foundation to result in vapor intrusion. In contrast, chlorinated solvents undergo limited biodegradation and can cause a vapor intrusion concern even when the original source is a relatively long distance away.

Seasonal variation can influence both the susceptibility of the building as well as the environmental conditions for vapor intrusion. During winter and summer months, fresh air exchange is reduced because buildings are generally closed more tightly for climate control. For residences during the winter months, a stack effect commonly results from the indoor to outdoor air temperature differential as well as the mechanics of many types of heating systems, which may increase vertical migration of contaminants.

3. Health Implications of VOCs in Indoor Air

There are three primary concerns associated with contaminant migration into indoor air. Chemical vapor intrusion poses the greatest immediate threat to health when there is a potential for fire and explosion. The second concern is for a high concentration, acute chemical exposure that could result in immediate health symptoms. The third concern is the possible cancer and non-cancer health effects caused by chronic long-term exposure to contaminants in indoor air. The fire and explosion hazard is by far the least likely to occur, while concerns regarding long-term exposure are the most common.

Risks from exposure to environmental contamination are quantified by estimating how much of a chemical is likely to enter the body based on how a particular resource is used. The assumptions used for estimating air exposures are more realistic than those used for other media. Breathing rates per body weight are generally uniform, with less variability than daily rates of water intake, for instance. People spend a predictable amount of time in their homes, and there are no alternatives for breathing air sources compared to contaminated drinking water (i.e. bottled water).

Fire and Explosion Hazards

Although uncommon, the potential for fire and explosion from vapor intrusion must not be ignored. The fire explosion concern is commonly raised with petroleum vapors because people associate the familiar smell with flammability. The lower explosive limit for gasoline vapor is 1.4%, or roughly 50,000 times higher than its corresponding odor threshold, making this an unlikely threat. However unlikely an explosion may be, the existence of vapors must be investigated. Fire and explosion hazards related to chlorinated solvent contaminants in indoor air are also unlikely. Very strong solvent odors would accompany flammable levels (>1000 times odor thresholds). In practice, the local fire department is usually called on to help address this concern. However, after the fire department clears the building of a fire and explosion hazard, an evaluation of acute and chronic health threats from chemical exposure must still be conducted.

Important Note: this document is not intended to address cases involving landfill or sewer gases. Contact the local fire department or agency staff directly with these issues.

Acute Health Effects

Vapors present in indoor air at concentrations below combustible levels may still pose a nuisance or health risk to residents. The most common symptoms people may notice from acute VOC exposures are: headaches, nausea, dizziness, and irritation of the eyes, nose, throat and lungs. Sensitivity to these effects can vary greatly from one person to the next. Individuals most affected by vapors are, usually, children, the elderly, and others with pre-existing respiratory problems such as asthma, bronchitis or emphysema. When building occupants experience health symptoms, the local health department or KDHE should be contacted for assistance.

KDHE has long utilized the Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk level (MRL) acute exposure concentrations as health protective values for air quality which are designed to prevent the most sensitive health effects over short exposure time frames. Occupational (OSHA) standards, though commonly available, should not be directly applied in a residential setting. They are established to protect a healthy adult worker population from work day exposures, and often incorporate some acceptance of health risk on the part of the worker. When more appropriate residential guidance is not available, the MRLs located on the ATSDR website (http://www.atsdr.cdc.gov/mrls.html) should be used as the appropriate residential screening value. However, if people are showing symptoms consistent with those expected for the contaminants present, KDHE will assume they could be related to chemical exposure until a physician's diagnosis can be obtained.

The irritating effects of acute VOC exposure usually diminish after exposure is stopped. If symptoms don't improve following exposure intervention, the health effect may be unrelated to VOC exposure. In all cases involving health effects from chemical exposures, the individuals should consult their physician.

Chronic Health Effects

In vapor intrusion cases, KDHE assessment is almost always driven by the presence of potentially carcinogenic or carcinogenic VOCs such as vinyl chloride, trichloroethylene (TCE), tetrachloroethylene (PCE), 1,2-dichloroethane, carbon tetrachloride, or benzene. Due to its comparatively high cancer potency, mobility in ground water, and high Henry's Law Constant, vinyl chloride may be a vapor intrusion concern at lower levels of environmental contamination more often than other chemicals. TCE and PCE also represent common concerns because of their widespread use, proximity of sites that utilize those chemicals to residential areas, and their high toxicity values relative to other common contaminants. Among non-carcinogens, naphthalene is the chemical that most commonly drives health concerns.

In a long-term residential exposure situation, benzene levels at the odor threshold (roughly 5 ppm) pose a significant increased cancer risk, more than one thousand times greater than health officials would permit in a drinking water exposure. Although benzene is rarely present above the odor threshold, its presence at harmful concentrations may still be suspected when the odors from other petroleum chemicals are noticed. Other components of petroleum, such as toluene, xylenes, and naphthalene can be smelled at very low concentrations. These low concentrations of odoriferous compounds *signal* the presence of benzene. When faint but perceptible gasoline odors are noticed, benzene levels can still be ten to one hundredfold higher than levels considered safe and appropriate for residential indoor air. Long-term exposures to these and related VOCs can also pose a risk of non-cancer health effects such as damage to the liver, kidneys, blood, nervous system, and others.

These non-cancer health effects are addressed concurrently by working to prevent the unnecessary cancer risks.

4. Evaluating Vapor Intrusion

With any concern of chemical vapor intrusion (including petroleum) it must be established whether or not the pathway for vapor intrusion is complete. For smaller sites, KDHE has taken the stance that where human interaction with contaminants is possible, the appropriate thing to do is sample where the exposure may be taking place (e.g. indoor air sampling). For larger sites, the vapor intrusion investigation may be done in another manner (e.g. soil gas/vapor sampling). For both of these investigative strategies, it is implied that there is enough data to have an idea of the aerial extent of the soil and ground water contamination present at the site or down-gradient of the site and significant preferential pathways (e.g. fractured bedrock, etc.) are not present. It is important to reiterate the screening criteria to determine those sites that vapor intrusion may be an issue. Buildings of concern will be within 100 ft. (for chlorinated VOCs) and 40 ft. (for petroleum hydrocarbons) laterally and 40 ft. or less vertically of the contamination. Investigating vapor intrusion sites should start in the known worst-case area and progress outward from there.

In the evaluation of this pathway, direct measurements under worst-case conditions is the best option, although flexibility may be granted due to certain site conditions. For large sites, a soil gas/vapor survey may be the most appropriate first step, followed by indoor air sampling. Sub-slab sampling should be considered anytime indoor air samples are collected.

- Starting with the axis of the plume at the point at which occupied buildings begin or where the structures reside over the highest concentrations of the ground water plume, a group of buildings should be selected (with KDHE/BER approval) for indoor air sampling or, for larger plumes, the neighborhood(s) should be selected for an alternate investigatory methodology (e.g. soil gas/vapor sampling).

Indoor Air Sampling

- A minimum of five structures should be selected for the initial sampling, unless there are fewer buildings potentially affected.

- Sampling should be performed in as many representative construction types (i.e., basement, crawlspace, etc.) as possible. Sampling should be performed utilizing six liter evacuated sampling canisters and analyzed utilizing the TO-15 or TO-15 SIM (selective ion method) methodologies. Samples should be collected from the lowest liveable level, basement, sub-slab, or crawlspace area and at least one outdoor ambient air sample.

- Samples from breathable air (non sub-slab) should be collected over 24 hour intervals using canisters equipped with flow regulators. The samples should be collected in the breathing zone, which is the area three to six feet off the floor. Canister vacuum readings should be taken prior to, and at the end of the sampling period. A positive vacuum reading must be maintained over the 24-hour period. Sub-slab samples should be collected using one-liter canisters, or smaller, and can be collected as grab samples. Multiple sub-slab samples may need to be collected to account for spatial variability.

- Buildings should be sampled under closed (usually winter and summer months) conditions. Crawlspaces should be closed prior to sampling. A building survey should be done prior to sampling to identify potential indoor background VOC sources.

Building occupants should be instructed to refrain from using products that may contain VOCs as well as remove VOCs that may interfere with the indoor air sampling. Abandoned, un-occupied buildings should not be included in the sampling plan, unless looking at a possible future use scenario. Sub-slab samples can be collected any time of year.

- Additional information on indoor air sampling and sub-slab sampling can be found in KDHE Standard Operating Procedures (SOPs) BER-33 and BER-34, respectively.

Soil gas/vapor sampling

- For larger sites it may be applicable to perform a soil vapor survey to pinpoint where actual indoor air testing may be required or show that vapor intrusion is not occurring. The KDHE project manager can assist with the applicability of soil gas/vapor sampling.

- Actual soil gas/vapor data are reflective of subsurface conditions, are less intrusive to residents, allow for real-time results, and may be less expensive than indoor air sampling. The number of samples required for a soil vapor survey will be greater than what is expected for an indoor air sampling event to account for spatial variability.

- Soil vapor data are a direct measurement of the contaminant that can potentially migrate into indoor air. Vertical profiles coupled with spatially sufficient horizontal soil vapor data can provide adequate evidence the vapor intrusion pathway may be incomplete or at a minimum reduce the number of structures to be sampled for indoor air.

- Vapor sampling will be done by either the post run tubing method or by installing vapor wells. Samples for off-site analysis will be collected in one-liter or smaller evacuated stainless steel canisters and analyzed by TO-14 or TO-15 methodologies. The KDHE project manager should be notified if on-site analysis is to be used and all methodologies must be pre-approved by the KDHE project manager.

- Additional information on post-run tubing sampling, field analysis, and vapor well installation can be found in KDHE SOPs BER-07, BER-25, and BER-35, respectively.

5. Indoor Air Sampling and Interpretation

Single or even multiple sampling events may not provide enough information to prove that unacceptable exposure won't occur. In such cases the cost of mitigation should be weighed against the cost of additional sampling (which could result in the need for mitigation anyway). There are a variety of monitoring methods available, each of which has its own strengths and weaknesses, and the KDHE Project Manager should be consulted prior to any sampling. For indoor air sampling KDHE considers stainless steel evacuated canisters to be the most reliable.

When planning an indoor air vapor intrusion investigation, begin with three basic questions: 1) Are chemical vapors entering the building(s)? To answer this question, samples may need to be collected inside the building. A time-integrated sample is the most appropriate for sample collection and, depending on construction type and building size, the number of samples per structure may vary. A soil gas survey may be used to potentially rule out vapor intrusion, providing adequate sampling coverage and results. 2) What is in the outside air? A majority of indoor air can be comprised of ambient outdoor air in addition to soil vapor. Indoor air samples without outdoor air samples can be difficult to interpret because it is common to have detectable VOCs in ambient outdoor air, particularly in industrial areas. 3) Is there a chemical exposure hazard? This is the most difficult question to answer, however, collecting the appropriate samples for the site will provide objective data when answering this question. Table 1 describes rationale for selecting samples and sampling locations.

Table 1
Rationale for Selecting Air Sample Locations

Where	*Why*
Crawlspace Air - Collect the sample from a central location if the crawlspace has a dirt floor. Vents in the crawlspace should be closed several days prior to sampling to ensure a worst-case sample.	Sampling of foundation air (e.g., subslab and/or crawlspace air) provides a direct measure of the potential for exposure from vapor intrusion. When collected in conjunction with indoor air sampling, foundation samples can be used to identify the exposures that originate from vapor intrusion and distinguish those due to background sources.
Subslab Air - Collect a sample or several samples from various locations in the slab. Possible entry points may be ideal sampling locations. Spatial variability must be accounted for.	Sampling of foundation air (e.g., subslab and/or crawlspace air) provides a direct measure of the potential for exposures from vapor intrusion. When collected in conjunction with indoor air sampling, foundation samples can be used to identify the exposures that originate from vapor intrusion and distinguish those due to background sources.
Basement Air - Collect a sample from an area where vapor entry may be expected, or from a central location if an obvious point of entry is unknown.	A sample of basement air can be used to demonstrate whether soil vapor is impacting the air of the home.
Lowest Liveable Area Air - Collect a sample from the breathing zone in a living area of the home. If the basement is finished and used, a sample should also be collected there. Avoid areas where moisture and other VOCs are present (e.g., kitchens, bathrooms, etc.).	This sample represents the air quality at a common point of exposure. However, multiple samples over time, taken at multiple locations, would be needed to determine actual exposures.
Outdoor Ambient Air - Collect a sample from a location upwind of the house(s) away from obvious VOC sources (parked cars, lawn mowers, garages, etc.).	This sample is very important, as indoor air contaminants may originate from outdoor air.

In summary, check with the KDHE project manager to determine an appropriate sampling approach for a given site. When indoor air sampling is performed, KDHE recommends a 24 hour time-integrated sample using evacuated stainless steel canisters using EPA Method TO-15 analysis (with the addition of a second source standard). Before samples are taken indoors, it is important to take a survey of the structure to note other potential VOC sources. Instruct building occupants to refrain from using such products prior to and during testing. It is helpful to note weather conditions and activities in the building so that the results may be more fully understood. The KDHE SOP BER-33 mentioned previously contains an inspection questionnaire that provides a useful checklist during the pre-sampling inspection. When results are received, they should be considered along with other equally important factors such as variability of the contaminant source, how representative the sample location is to other areas of the structure, how the areas are used, and other site-specific issues that all combine to shape the level and frequency of long-term exposure.

If the building is served by a private well, it is important to note that any VOCs in the well water can contribute to the indoor air concentrations. It is difficult to distinguish between the two sources and a remedy for the well water should be performed prior to air sampling.

KDHE has developed indoor air screening values that can be found in the RSK manual, 4th version, June 2007, Appendix A-2. The values are exposure point concentrations for indoor air of residential scenarios. If indoor air sampling is performed, a direct comparison to these numbers is applicable. If sub-slab sampling or soil gas sampling is performed, then the use of an attenuation factor should be applied. Check with the KDHE project manager for direction on the use of attenuation factors. Currently media specific attenuation factors set by EPA (0.1, 0.01, and 0.001 / sub-slab, 10-15 ft. soil gas, and groundwater, respectively) or other regulatory agencies may be used, with prior approval from KDHE/BER. A detailed discussion on attenuation factors can be found in the Interstate Technology and Regulatory Council's (ITRC) Technical and Regulatory Guidance document, *Vapor Intrusion Pathway: A Practical Guide* (VI-1, 2007), Appendix H.1.1.

6. Soil Vapor Sampling and Interpretation

Soil vapor sampling is generally used to focus a subsequent indoor air investigation, however, there are chances that the pathway can be ruled incomplete based on soil vapor sampling results. Enough data points need to be collected to determine soil vapor concentrations horizontally and vertically to adequately rule out the possibility of vapor intrusion. Working from the highest concentration area to the lowest concentration is recommended for vapor intrusion studies. There are a variety of soil vapor sampling methods available, however KDHE has determined that the post-run tubing method and the installation of vapor wells to be the only acceptable ways to collect reliable soil vapor samples. In certain circumstances, field analysis can be substituted for off-site analysis. For on-site analysis, a minimum of 10% of the samples analyzed will be verified off-site with stainless steel evacuated canisters.

7. Vapor Intrusion Modeling

The most common vapor intrusion models are deterministic, having single point inputs and outputs. They are most applicable under homogeneous site conditions with uniform building construction features, and least applicable under variable conditions (which occur at most sites). Using the range of potential input assumptions that match the range of site conditions (various soils encountered, ranges of contaminant concentrations, etc.), these models can predict wide ranges of potential indoor air impacts spanning orders of magnitude.

It is important to note that models do not incorporate preferential migration pathways such as foundation drain tile and sumps, utility corridors, or various older foundations types. Due to these limitations, direct measurements (e.g., indoor air samples, crawlspace, sub-slab, soil vapor, etc.) are the preferred method of determining vapor intrusion concentrations.

8. Use of Screening Values for Environmental Media

A number of states use screening values for other contaminated environmental media to determine if the vapor intrusion pathway warrants further consideration. These table values contain minimum ground water and soil contaminant levels and are generally calculated from a vapor intrusion model using a set of generic exposure assumptions. Due to the variability of sites, KDHE does not use these types of screening values generically across the state and therefore does not allow them to be used to evaluate health risk at sites in Kansas.

9. Preventing Vapor Intrusion

Two separate but equally important approaches to preventing chemical vapor intrusion are source control and air quality mitigation. How the two approaches are used together depends on the conditions of the site and whether or not the pathway is already completed. As a general rule, KDHE recommends interrupting the migration pathway as far away as possible from points of human exposure. It is important to note that any action taken to remediate environmental contamination must be performed in coordination with KDHE.

The first and most traditional approach is to control the source of the contamination so that the contaminant migration pathway does not reach the building in question. This source control activity is usually designed to prevent ground water contamination that would exceed drinking water standards. The same approach applies to preventing vapor intrusion originating from contaminated ground water. Controlling soil gas migration is also an important source control activity, especially when the contaminants are migrating through soil gas directly from the source. When contaminants have reached a building, source control is still necessary and important, but mitigating indoor air impacts becomes a more immediate priority. Ultimately, source control efforts should remove the need for mitigation at the building(s).

When contaminants are entering a structure, steps should be taken to seal any gross openings that allow for direct soil vapor intrusion. These include openings in the slab, major cracks in floors and walls, gaps around utility lines, open sumps, compromised floor drains, etc. For structures with crawlspaces, installation of a vapor barrier is recommended. If odors are apparent, the basement/crawlspace air should be ventilated separately, as much as possible, from the remaining occupied portions of the building (closing cold air returns and heat vents in the impacted area). If ventilation of the crawlspace and/or basement is performed, freezing of water pipes is a possibility and care must be taken with this approach. The remaining mitigation steps involve creating a pressure differential between the indoor air and soil gas that prevents vapor migration into the structure. The most common mitigation techniques utilize the types of sub-slab depressurization systems developed to prevent radon gas migration. These systems tend to be relatively inexpensive (compared to an indoor air investigation and other aspects of site remediation) because they can be adapted to take advantage of existing building features. A list of radon contractors can be obtained by filling out a request form located on the KDHE Bureau of Air and Radiation (BAR) website: http://www.kdhe.state.ks.us/pdf/bar/order.pdf.

A comprehensive review of mitigation strategies can be found in Chapter 4 of the ITRC Technical and Regulatory Guidance document, *Vapor Intrusion Pathway: A Practical Guide* (VI-1, 2007).

10. Vapor Intrusion and Property/Brownfields Redevelopment

Questions about vapor intrusion can come up as part of redevelopment on properties with residual VOC contamination. When the issue is addressed prior to final building design and construction, more options are available. Good characterization of the extent and magnitude of contamination is important. With knowledge of the extent of contamination, additional remedial work can be performed to accommodate building construction, or building design can be modified to accommodate residual contamination left in place. The ideal situation would be complete remediation of the contaminant source(s) coupled with incorporation of some vapor mitigation system elements into the building construction. Just like radon, it is very difficult to predict indoor air concentrations from a vacant lot, and it would require testing after the building was completed and occupied. Useful information on pre-construction mitigation techniques (a.k.a. Radon Resistant New Construction - RRNC) is available on the following EPA website and in related documents such as "Building Radon Out": http://www.epa.gov/iaq/radon/contruc.html.

11. Additional Links and Resources

Further reading and additional guidance documents can be found at:

- The State of Wisconsin Department of Health and Family Services, Division of Public Health has completed a useful and detailed guidance document on vapor intrusion and indoor air evaluations. The full document, "*Chemical Vapor Intrusion and Residential Indoor Air", Guidance for Environmental Consultants and Contractors*, released February 2003 is available on their website at: http://www.dhfs.state.wi.us/eh/Air/pdf/VI_guide.pdf.

- The State of Massachusetts Department of Environmental Protection has also released a detailed guidance document titled, "*Indoor Air Sampling and Evaluation Guide*," April 2002. Available at: http://www.state.ma.us/dep/ors/orspubs.htm#air.

- Information on investigational techniques and strategies can be found in the Interstate Technology and Regulatory Council's (ITRC) Technical and Regulatory Guidance document, *Vapor Intrusion Pathway: A Practical Guide* (VI-1, 2007), and a companion document, *Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios* (VI-1A, 2007). These two documents are located at: http://www.itrcweb.org/vaporintrusion.